BELLCOMM, INC. 29p

SUBJECT: The Effects of Changing the Launch Azimuth Limits on the Launch Window, Launch Vehicle Payload, and Communications and Tracking Coverage-Case 310

DATE: April 6, 1967

FROM: T. B. Hoekstra

ABSTRACT

In order to lengthen the daily launch windows for Apollo lunar landing missions, the 72° and 108° launch azimuth limits could be extended. This memorandum presents an analysis of the effects such a change would have on the daily launch windows, the launch vehicle payload, and the communication and tracking times for insertion, parking orbit, and translunar injection. Although this work was initiated to evaluate a possible widening of the launch azimuth limits, much of the basic material applies to narrowing the limits as well.

It has been determined that extending the launch azimuth limits to 60° and 120° can lengthen the launch window by over two hours. However, using a single insertion tracking ship, capable of covering a 26° range in azimuths, there is only about a 10% probability that an additional hour of launch window time will be provided with the extended launch azimuth limits. The launch vehicle payload loss with the 60° launch azimuth (compared to the case of a 90° launch azimuth) is 2500 pounds while with a 72° launch azimuth the loss is 930 pounds. If both an Indian Ocean and a Pacific Ocean tracking ship are provided, good communication and tracking coverage is available during the first and second parking orbits for any launch azimuth between 60° and 120°. Coverage on the third parking orbit is marginal for launch azimuths greater than 110° even if the two tracking ships are utilized. Ground tracks during Saturn V powered flight for azimuths between 60° and 72° tend to pass over fewer land masses than those for azimuths between 108° and 120°.

If it is desired to lengthen the daily launch window, on the basis of this analysis it seems reasonable to extend the somewhat arbitrary 72° and 108° limits to perhaps 65° and 110° respectively.

BELLCOMM, INC.

SUBJECT: The Effects of Changing the Launch Azimuth Limits on the Launch Window, Launch Vehicle Payload, and Communications and Tracking Coverage-Case 310

DATE: April 6, 1967

FROM: T. B. Hoekstra

MEMORANDUM FOR FILE

INTRODUCTION

Expanding the limits on the launch azimuth beyond the range from 72° to 108° east of north has a number of effects upon the mission. As the launch azimuth limits are extended, the launch window duration is increased since it is possible to obtain earth parking orbit planes which intersect the moon over a longer period of time. Launching with a 90° launch azimuth takes full advantage of the spin of the earth; any deviation from 90° brings with it an associated payload loss and this loss increases as the deviation from 90° is increased. Extending the launch azimuth range therefore increases the chances for large payload losses. In addition, the communication and tracking coverage times may be decreased as the launch azimuth limits are extended since the ground tracks pass over many areas not passed over with the smaller azimuth range.

This memorandum presents an analysis of the magnitudes of these changes and the limitations on the mission which they cause.

LAUNCH WINDOW CONSIDERATIONS

General Analysis

The earth parking orbit plane for a lunar mission should be oriented such that it contains the expected location of the moon when the spacecraft arrives in the vicinity of the moon. Knowing this, it is possible to find the desired launch azimuth at any time. Throughout the day, as the moon moves in its orbit and the earth spins under it, the desired launch azimuth would vary over a 180° range. In the past, limits of 72° and 108° east of north have been placed (somewhat arbitrarily) on the launch azimuth. This, of course, gives rise to limits on the times during the day when launches can take place. The times during the day when it is possible to launch are called daily launch windows. Two windows occur each day since the plane passing through Cape Kennedy with a given inclination will pass through the moon twice a day. If no more than three earth parking orbits are considered, injection from the earth parking orbit to the translunar trajectory occurs in two general areas, one over the Atlantic Ocean, one over the Pacific Ocean. The corresponding launch windows are termed Atlantic and Pacific. The length of the maximum daily launch window with the 72° and 108° launch azimuth limits is approximately 4-1/2 hours.*

Since the probability of a launch increases as the launch window is lengthened, it has been suggested that the azimuth limits be extended (to 60° and 120° for example) to lengthen the launch window. A change to launch azimuth limits of 60° and 120° would lengthen the maximum launch window to about 6-3/4 hours. Figure 1 illustrates how the maximum launch window varies as the launch azimuth sector varies (centered about the 90° launch azimuth).

Not only is the total duration of the launch window important but the variation of the launch azimuth throughout the launch window is also important. Figure 2 shows the launch azimuth as a function of elapsed time after the opening of the launch window, it applies to both Atlantic and Pacific windows. Reading the abscissa and ordinate appropriate for the Atlantic or Pacific window provides the distinction between these two cases. This figure clearly shows the effect of the lunar declination on the behavior of the azimuth. When the declination is near zero the azimuth increases at a nearly constant rate. When the declination is only slightly less than the latitude of the launch pad, the azimuth increases slowly through most of the window but quite rapidly at either the beginning or the end of the window. When the declination is greater than the latitude of the launch pad, the curve represents a double valued function.

The double-valued nature of the azimuth-time variation could lead to difficulty in booster guidance implementation. In addition, when the moon's declination is greater than the launch pad latitude, the duration of the launch window

---

* In this analysis the moon is assumed to remain fixed in space throughout the duration of the launch window. The horizontal and vertical motions of the moon, relative to the earth's latitude lines, can cause as much as a 6-7% increase in the duration of the launch window when the moon is near its ascending node (relative to the Earth's equator) for Pacific injections or near its descending node for Atlantic injections.

is slightly decreased. Although the declination of the moon can only exceed the latitude of the launch site by about 1/4° it does so at some time during many of the monthly launch opportunities between March, 1968 and March, 1970 and deserves further discussion.

The earth's equator is inclined about 23-1/2° to the ecliptic and the plane of the moon's orbit around the earth is inclined just over 5° to the ecliptic. Since the moon's orbit plane precesses, the inclination of the moon's orbit to the equator can vary between about 18-1/2° and 28-1/2°. A complete cycle of this inclination variation occurs in about 18 years with a maximum inclination of 28.7235° occurring in late March, 1969. The minimum inclination occurs in 1978. Since the geocentric latitude of Pad A, Complex 39 is 28.4471° (the geodetic latitude is 28.6084°) the declination of the moon can exceed the latitude of the launch pad and thus give rise to the double valued azimuth functions shown in Figure 2.

Figure 3, showing the lunar orbit inclination to the earth's equator from February, 1968 to May, 1970, shows that the <u>inclination</u> of the orbit can exceed the pad latitude only from March, 1968 to March, 1970 (with the major period of trouble occurring between August, 1968 and November, 1969). This means that the <u>declination</u> of the moon can exceed the pad latitude only during this period of time. Of course, the magnitude of the declination of the moon must be greater than the pad latitude when the spacecraft arrives in the vicinity of the moon for the difficulty to arise. Since the average monthly launch opportunity lasts from 8 to 10 days and the moon moves around its orbit (from maximum declination to minimum declination and back to maximum declination) in about 27.2 days, the probability that the magnitude of the declination will exceed the pad latitude in the 1968-1970 time period would seem to be high. In fact, at some time during over 70% of the monthly launch opportunities between late August, 1968 and October, 1969, the magnitude of the moon's declination exceeds the pad latitude. The magnitude of the moon's declination exceeds the pad latitude for up to a full day during certain of these monthly launch opportunities.

Although the double-valued launch azimuth function which arises in such cases may lead to difficulty, it seems reasonable to use that portion of the azimuth versus time curve which is monotonically increasing or decreasing. For example, even if the lunar declination were 29°, Figure 2 shows that the first 5.9 hours of the launch window could be used (while only 24° of azimuth change is needed). The nearly infinite slope at the end of such a window would correspond to a nearly constant launch azimuth with respect to time.

Choosing Launch Window Segments

Although it has been found that a 6-3/4 hour launch window is available if the launch azimuth limits of 60° and 120° are employed, at least two factors can preclude the use of the full window. The first factor is that three minutes of tracking coverage is desired immediately after earth parking orbit insertion (Reference 1) and this tracking is obtained by a ship having an effective launch azimuth coverage range of only 26° for a 5° masking angle. The second factor is the previously mentioned fact that the desired launch azimuth varies in a non-uniform fashion as time passes during a launch window. When azimuth changes very rapidly, the fitting of certain polynomials associated with booster guidance becomes more difficult; also since the inertial platforms are aligned along the flight azimuth, rapid changes in azimuth will increase the initial alignment errors. Both of these factors suggest choosing a portion of the launch window which minimizes the azimuth sector used for a given duration segment of the launch window. This azimuth sector will be termed "best".

A computer program was written to determine the minimum azimuth sector (located somewhere between 60° and 120°) for given duration launch windows. The results of computations for various lunar declinations and 2.5, 3.5, 4.5 and 6.0 hour windows are shown in Figure 4. This figure shows that Pacific windows favor the lower numerical launch azimuths for positive lunar declinations while at the same time the Atlantic windows favor the higher numerical azimuths.

Once the "best" azimuth ranges are known as a function of lunar declination, it is possible to plot the preferred launch azimuth sector as a function of date throughout any month. Due to the lunar lighting constraint, which requires that the sun must be between 7° and 20° above the eastern horizon of the moon at the time of lunar touchdown (Reference 2), launches can only occur on 8 to 10 days per month. This 8 to 10 day period is termed the monthly launch opportunity. Figures 5 and 6 show, as examples, the preferred azimuth bands for the February and August, 1968 launch opportunities utilizing the Pacific launch window. The Atlantic window curves would be mirror images of these curves about the 90° azimuth line.

This brings up the question of whether choosing the "best" azimuth sector significantly increases the probability of having a certain length launch window. For instance, is there a significantly greater probability of having a four hour launch window when the "best" azimuth range is chosen as opposed to the case when the azimuth limits are fixed inflexibly? Figure 7 shows the probability of having a given launch window duration when the azimuth ranges are chosen by different methods and between different extreme limits.

Curve A shows that the launch window is always greater than two hours, but never more than 4.5 hours, if the 26° range at either end of the current 72° to 108° range is inflexibly chosen. If the center 26°, from 77° to 103°, is inflexibly chosen, Curve B shows that a constant 3.4 hour window would be available. Choosing the "best" 26° azimuth spread between 72° and 108° would provide launch windows between 3.4 and 4.5 hours in duration as shown by Curve C. Curve D shows that if the "best" 26° is chosen with no upper and lower azimuth limits, launch windows lasting up to 6.1 hours can be obtained. Although no azimuth limits are imposed in this case, the azimuth does not go beyond the range 60° ≤ azimuth ≤ 120°. Curves C and D provide a good means of comparison between the launch windows obtained using the widened azimuth limits and those obtained with the 72° and 108° limits. There is only about a 10% probability that an additional hour of launch window is obtained with the 60° and 120° limits. Curve E shows that if the 36° launch azimuth range between 72° and 108° could be covered by one tracking ship a 4.5 hour launch window would be assured (unless the declination of the moon is greater than the pad latitude in which case a slight decrease in launch window duration would occur). Finally, Curve F shows that the launch window lasts between 4.5 and 6.7 hours if the "best" 36° segment is chosen between 60° and 120°.

Thus, Figure 7 shows that moderate gains in launch window duration can be realized by extending the launch azimuth limits beyond the current 72° to 108° values and by choosing the "best" launch azimuth sectors within these limits.

LAUNCH VEHICLE PAYLOAD LOSS

Since the launch vehicle payload decreases rapidly as the launch azimuth deviates from 90° (due east), any additional launch window obtained by extending the launch azimuth limits beyond the 72° to 108° range is obtained at considerable expense in launch vehicle payload. Figure 8 shows how the payload loss varies with launch azimuth. For the 72° to 108° azimuth limits, the maximum payload loss compared to 90° would be about 930 pounds; with the 60° to 120° limits, the maximum payload loss would be about 2500 pounds.

Once the payload loss for any launch azimuth is known, it is possible to find the maximum payload loss for a given range of launch azimuths. Using various strategies for choosing the launch azimuth range it is then possible to calculate the probability of having a certain payload loss for each of these strategies. The results of these calculations are shown in Figure 9. For example, if the 26° range from 77° to 103° is rigidly chosen there is a constant 500 pound maximum payload loss (Curve B, Figure 9). On the other hand, if the "best" 26° between 72° and 108° is chosen, Curve C shows that 40% of the time 900 pounds, or more, would be lost compared to the 90° launch azimuth case. Curve D shows that, if the "best" 26° azimuth range is chosen with no azimuth limits (the azimuth still remains within the range $60° \leq$ azimuth $\leq 120°$), 40% of the time at least 1700 pounds of payload would be sacrificed relative to the 90° launch azimuth case.

COMMUNICATIONS AND TRACKING

Extending the launch azimuth limits beyond the present 72° to 108° range expands the area on the earth's surface which may be overflown by the space vehicle. The communications and tracking network was set up to provide adequate coverage for lunar missions having launch azimuths between 72° and 108°. Thus, communication and tracking coverage must be analyzed during insertion into earth parking orbit, during earth parking orbit, and during translunar injection to determine how the communication and tracking requirements place restrictions on the expansion of the launch azimuth range.

Earth Parking Orbit Insertion Coverage

As mentioned previously, it is felt that continuous tracking is needed above a 5° masking angle for the first 3 minutes following insertion into earth parking orbit (Reference 1). A single ship can cover a maximum azimuth sector of about 26° while providing a minimum of 3 minutes of coverage if it is located at the center of the 26° sector approximately 1900 n. mi. downrange. The dashed lines in Figures 5 and 6 show how this 26° sector moves throughout the February and August, 1968 launch opportunities for Pacific injections. The ship movement rate lines show that the tracking ship would have no difficulty following the preferred azimuths if the Pacific (or Atlantic) windows were consistently chosen. If the Atlantic and Pacific windows were alternately chosen, the tracking ship quite possibly would not be able to cover the "best" azimuths for both. In such a case some deviation from the "best" azimuth sectors would be necessary.

If insertion tracking times other than 3 minutes are considered, the azimuth sector which a single tracking ship can cover varies greatly. Figure 10 shows the relationship between the minimum insertion tracking time and the azimuth range covered when first contact is made 1400 n. mi. downrange (the approximate powered flight cutoff point). For example, 36° of azimuth could be covered if only 1-3/4 minutes of tracking were needed.

If two ships were employed to cover the entire 60° azimuth sector from 60° to 120°, each ship would be required to cover only 30° and thus could provide over 2-1/2 minutes of coverage without moving at all.

By comparing Curves B and E as well as Curves D and F in Figure 7, it becomes evident that the insertion tracking requirements have a significant influence upon the duration of the launch window.

Earth Parking Orbit Coverage

Communications and tracking during the earth parking orbit phase of the mission is provided by the 14 Unified S-Band (USB) stations on land and by several tracking ships. The locations of the USB stations are given in Table 1. The current operational constraints specify that at least two tracking, command, telemetry, and voice contacts of four minutes minimum duration above 5° elevation are needed for each revolution before translunar injection (Reference 1). In addition, at least one contact of four minutes minimum duration above 5° elevation is thought to be necessary between 90 and 30 minutes before translunar injection ignition with a station having command, telemetry, and voice capability (Reference 1).

Using the results of a previous study for launch azimuths from 72° to 108° (Reference 3) and extending these results to include azimuths from 60° to 120°, it is possible to plot the number of tracking stations passed on the first, second, and third revolutions* giving more than four minutes of coverage time for various launch azimuths. Figure 11 shows such plots accounting only for tracking by the 14 land stations. The plots in Figure 12 were constructed assuming that one minute of tracking was sufficient rather than four minutes.

It is clear that missions launched with azimuths from 60° to 90° are afforded much better coverage than those launched with azimuths from 90° to 120°, especially on the

* A revolution ends as Cape Kennedy's longitude is passed.

second and third revolutions. The inclusion of tracking ships can improve the coverage considerably if they are appropriately placed. As indicated by the lines denoted by IOS above the plots in Figures 11 and 12, a single ship located in the Indian Ocean about 300 miles south of Mauritius (with coordinates 25°S, 53°E) provides four minutes of first revolution coverage for launch azimuths between 82° and 102°, second revolution coverage from 60° to 120°, and third revolution coverage from 78° to 110°. Similar lines are shown indicating the coverage provided by a ship, denoted by POS, located in the Pacific Ocean with coordinates of 25°N, 127°W.

The Indian Ocean ship is purposefully located such that good coverage is given on the second and third revolutions where it is most needed. Since the Pacific Ocean ship is passed at the end of the third revolution where it does little good, it was positioned to optimize second revolution coverage.

The location of the insertion and reentry tracking ships is such that they do not provide any significant increases in tracking coverage where it is most needed (such as for launch azimuths above 100° on the third parking orbit).

The requirement for four minutes of command, telemetry, and voice contact between 90 and 30 minutes before translunar injection (TLI) cannot be entirely satisfied by the 14 land stations alone. The lines in Figures 13 and 14 bound the areas in time and launch azimuth from which TLI should not occur because four minutes (or one minute in the case of Figure 14) of contact was not made between 90 and 30 minutes before that time. It is clear that injections on the third parking orbit with launch azimuths above 100° encounter the most difficulty. An Indian Ocean tracking ship (25°S, 53°E) and a Pacific Ocean tracking ship (25°N, 127°W) would leave only the shaded areas in Figures 13 and 14 undesirable from a pre-injection communications standpoint. Clearly the only significant problem occurs for Pacific injections on the third revolution from parking orbits initiated with launch azimuths greater than 110°.

Post Translunar Injection Coverage

There is an additional operational constraint stating that continuous tracking, telemetry, and voice contact are required for a ten-minute period within the first twenty minutes after TLI cutoff (Reference 1). From a coverage standpoint it is quite advantageous to choose the final ten minutes of the twenty-minute period immediately following TLI cutoff since the coverage circle for a given station expands rapidly as the spacecraft moves away from the earth.

Using ground tracks and tracking coverage maps from a previous study (Reference 4, Figure 9) dealing with the 72° to 108° azimuth range and extending these results to cover launch azimuths from 60° to 120°, it can be concluded that the ten-minute period from ten minutes after TLI cutoff until twenty minutes after TLI cutoff is continuously covered provided that the Indian Ocean tracking ship is available. If the Indian Ocean tracking ship cannot be provided, certain missions utilizing the Atlantic launch windows would not receive ten minutes of post-injection coverage.

RANGE SAFETY PREFERENCES

The 72° and 108° limits on launch azimuth were originally set up to minimize the overflying of land masses during Saturn V powered flight. If the launch azimuth is allowed to increase beyond 108° by only a few degrees, a number of the West Indian Islands would be along the ground track of the powered trajectory. To the north of the 72° azimuth, Bermuda is the only land mass which would be overflown (when the launch azimuth is approximately 70°) until the Azores would fall along the ground tracks, far downrange, for launch azimuths less than about 65°. In this sense, the launch azimuths below 72° would be favored over those greater than 108°.

SUMMARY AND CONCLUSIONS

Extending the launch azimuth limits from the current 72° to 108° range has a number of effects on the mission. Additional launch time flexibility is provided by the lengthened launch window and longer holds could be tolerated before the mission would have to be scrubbed. On the other hand, severe payload losses are experienced when the launch azimuth approaches 60° or 120°. In addition, communications and tracking coverage becomes more critical as the azimuth limits are extended. Overflying large land masses is not a problem if the launch azimuth does not go beyond the 60° to 120° limits although between 110° and 120° a number of islands lie on the ground track of the space vehicle.

The following conclusions can be stated:

(1) The maximum launch window increases from 4-1/2 hours to 6-3/4 hours when the azimuth limits are extended from the 72° - 108° range to the 60° - 120° range.

(2) If the maximum azimuth sector to be considered is 26° (dictated by the insertion ship tracking coverage), significant increases in the duration of launch windows can be realized if the "best" 26° range is chosen rather than

"any" 26° range whether the 72° - 108° azimuth limits or any other wider limits are used.

(3) If the maximum azimuth sector to be considered is 26° and if the 60° and 120° azimuth limits replace the 72° and 108° limits, there is only about a 10% probability that the launch window duration will be increased by as much as one hour (since, in this case, the primary restriction on the launch window duration is provided by the 26° maximum azimuth sector rather than the overall azimuth limits).

(4) The payload losses for launch azimuths beyond the 72° - 108° range are significantly greater than those for azimuths within the 72° - 108° range with 2500 pounds being lost with a 60° launch azimuth (relative to the 90° azimuth) while only 930 pounds are lost with a 72° launch azimuth.

(5) Launch window durations can be significantly increased if less than three minutes of insertion tracking will suffice (i.e., the effective azimuth spread covered by a single ship is expanded) or if more than one insertion tracking ship is employed.

(6) Only for launches with azimuths between 60° and about 88° can the 14 USB land stations provide two or more four-minute tracking passes on each of the first three parking orbits.

(7) Injections occurring on the third revolution from earth parking orbits initiated with launch azimuths greater than 100° do not receive four minutes of tracking from the 14 USB land stations between 90 and 30 minutes before translunar injection.

(8) The addition of an Indian Ocean tracking ship (25°S, 53°E) and a Pacific Ocean tracking ship (25°N, 127°W) extends the upper limit in conclusion (6) to 99° and the limit in conclusion (7) to 110°.

(9) Continuous post-injection tracking and communications can be obtained from ten minutes after translunar injection cutoff until twenty minutes after translunar injection cutoff for any launch azimuth between 60° and 120° for injection on any of the first three parking orbits provided an Indian Ocean tracking ship is available.

(10) If the ground tracks are to avoid overflying land as much as possible early in the mission, extension of the

azimuth limits below the 72° value is favored over extending the upper limit beyond 108°.

In light of the above conclusions, an increase in launch window duration seems most reasonably achieved by extending the lower azimuth limit to perhaps 65° while extending the upper limit to 110°. The lower limit is here determined largely by tolerable payload losses; the upper limit is constrained by communication and tracking requirements during earth parking orbit and by the desire to avoid over-flying land masses during powered flight. To take full advantage of the expanded azimuth range, the present insertion ship tracking requirements should be critically examined with a view toward expanding the usable daily azimuth sector. In all cases the "best" azimuth sector should be chosen within the azimuth limits so as to maximize the launch window duration.

T. B. Hoekstra

2013-TBH-wcs T. B. Hoekstra

Attachments
References
Table 1
Figures 1-14

Copy to
See next page

Copy to
Messrs. R. O. Aller - NASA/MAO
J. K. Holcomb - NASA/MAO
T. A. Keegan - NASA/MA

A. G. Griffin - KSC/HC
R. D. Harrington - KSC/HC
R. E. Moser - KSC/HC

J. R. Elk - MSC/FM5
M. P. Frank - MSC/FM5
M. V. Jenkins - MSC/FM
C. H. Perrine - MSC/PM2
R. G. Rose - MSC/FA3
R. J. Ward - MSC/EP4

R. E. Beaman - MSFC/I-V-E
L. B. Bell - MSFC/I-V-E
E. T. Deaton - MSFC/R-AERO-DA
L. L. McNair - MSFC/R-AERO-P
F. A. Speer - MSFC/I-MO-MGR

D. R. Anselmo
C. Bidgood
J. O. Cappellari, Jr.
C. H. Eley, III
D. R. Hagner
J. J. Hibbert
W. C. Hittinger
B. T. Howard
B. Kaskey
W. D. Kinney
J. P. Maloy
J. Z. Menard
I. D. Nehama
J. T. Raleigh
I. M. Ross
R. V. Sperry
T. H. Thompson
R. L. Wagner
All Members, Department 2013
Department 1023 COPY TO
Central Files

REFERENCES

1. Hodge, John D., letter to FA/Technical Assistant for Apollo, "Flight Control Division operational constraints for Mission AS-504A", June 8, 1966, pp. 1-2.

2. Mayer, John P., "Constraints for AS-504A", NASA Memorandum 66-FM51-58, March 14, 1966, pp. 3-4.

3. Maloy, John P., "Unified S-Band Tracking and Communications Coverage of the Manned Space Flight Network During Eighteen Earth Revolutions at 105 NM Altitude for Launch Azimuths at 72, 80, 90, 100, and 108 Degrees - Case 320", Bellcomm Memorandum for File, September 20, 1966.

4. Taylor, James J., "Translunar Injection Positions for 1968 and 1969", MSC Internal Note No. 66-FM-42, April 20, 1966, pp. 33-38.

Table 1 - UNIFIED S-BAND STATIONS

STATION	LONGITUDE	LATITUDE
Grand Bahama Isl.	78.15W	26.65N
Bermuda	64.66W	32.35N
Antigua	61.75W	17.02N
Canary Isl.	15.60W	27.74N
Ascension	14.33W	7.96S
Madrid	4.17W	40.46N
Carnarvon	113.72E	24.91S
Guam	144.73E	13.31N
Canberra	148.98E	35.60S
Hawaii	159.67W	22.13N
Goldstone	116.87W	35.34N
Guaymas	110.72W	27.96N
Texas	97.38W	27.65N
Merritt Isl.	80.69W	28.51N

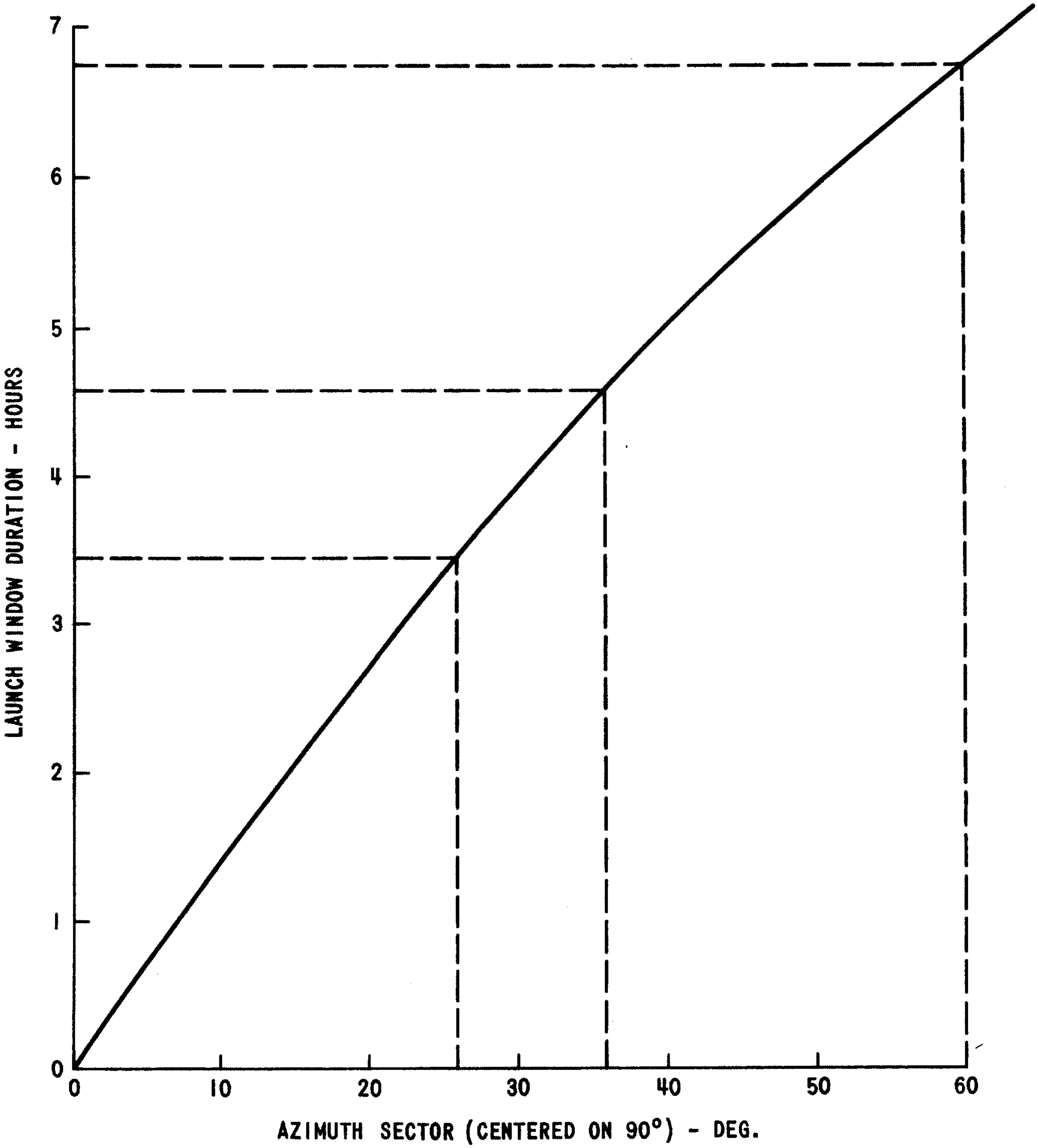


FIGURE 1 - LAUNCH WINDOW DURATION FOR VARIOUS LAUNCH AZIMUTH SECTORS
(AZIMUTH SPREAD CENTERED ON 90°)

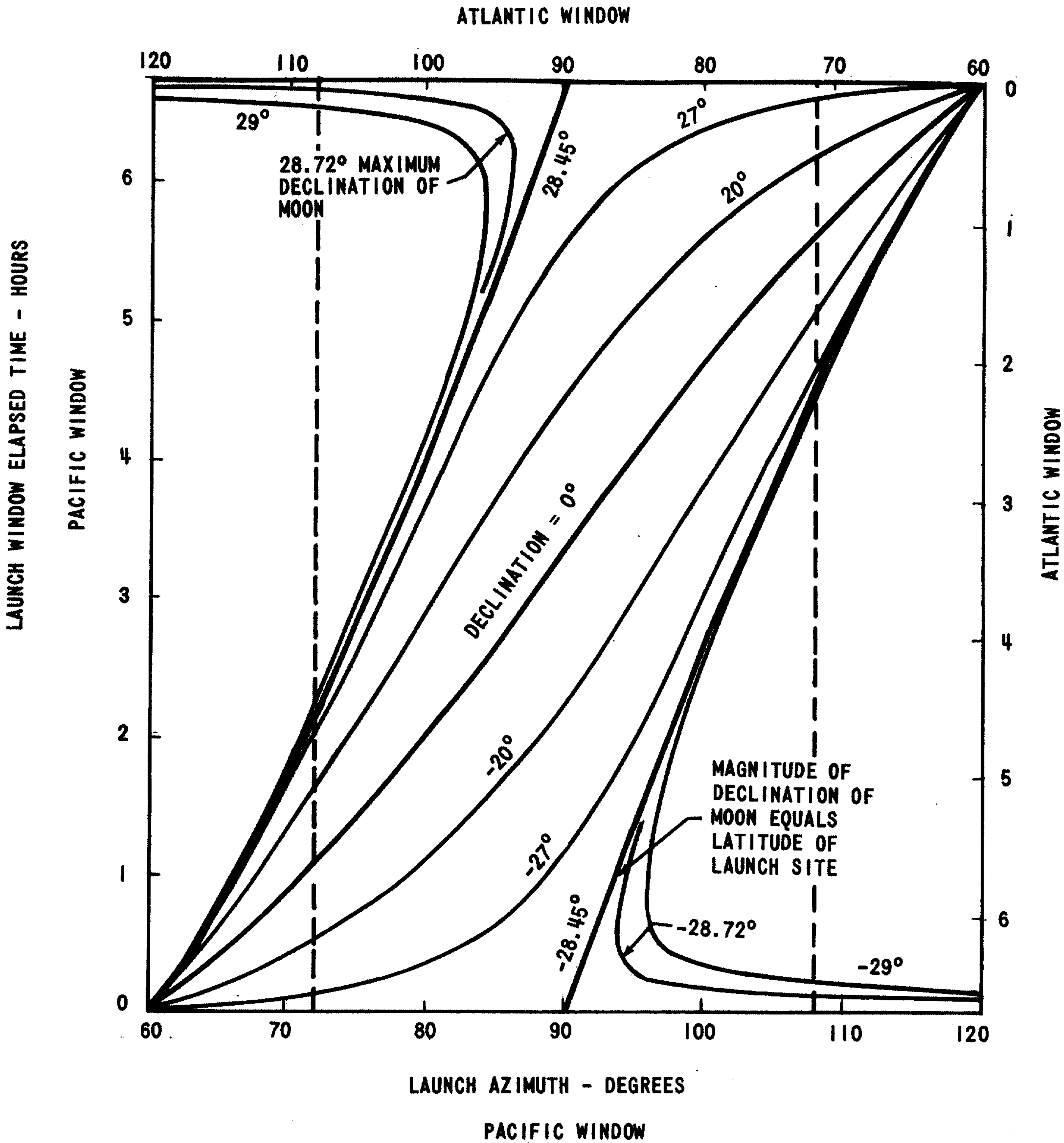


FIGURE 2 - LAUNCH WINDOW ELAPSED TIME VS. LAUNCH AZIMUTH

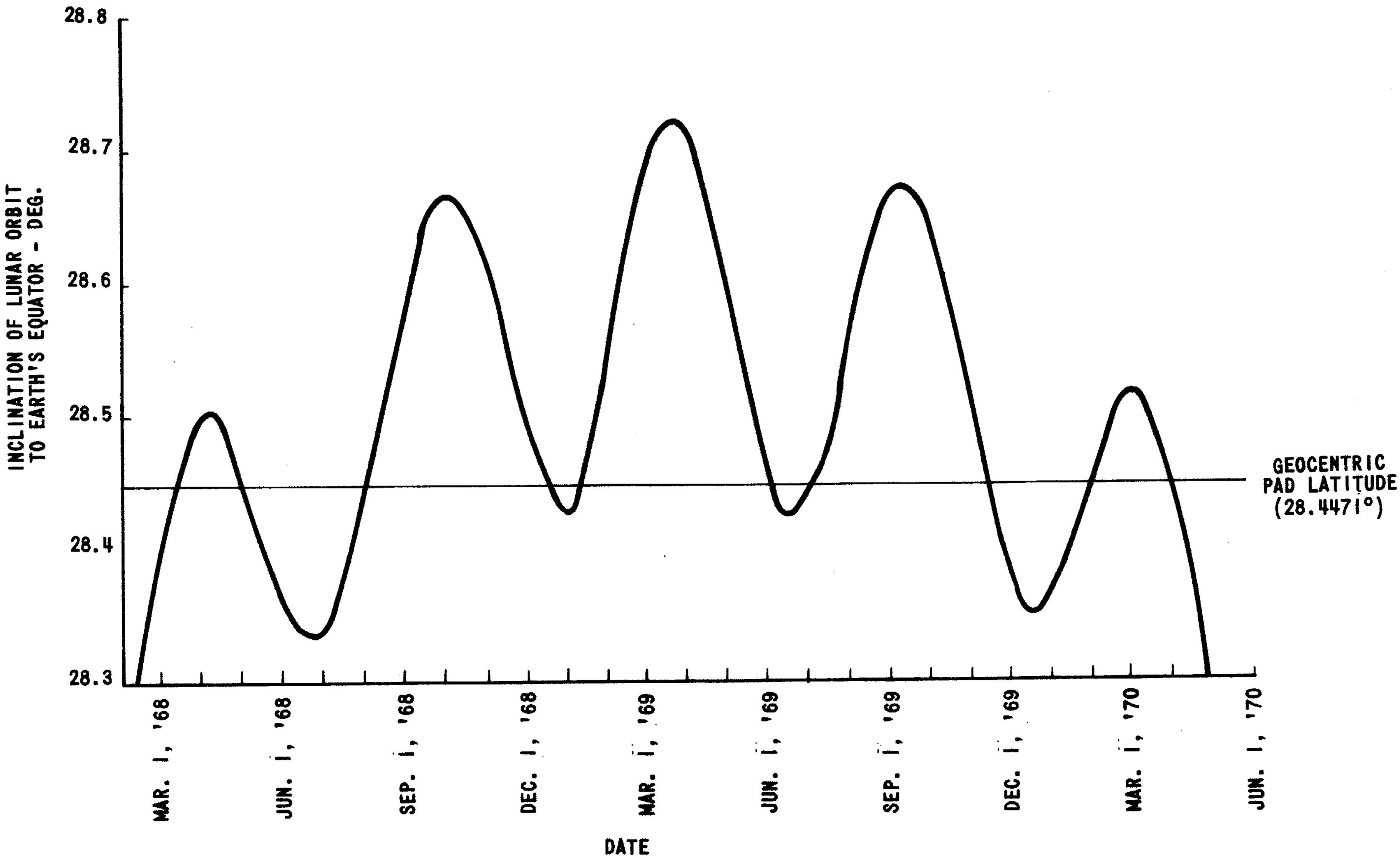


FIGURE 3 - INCLINATION OF LUNAR ORBIT TO EARTH'S EQUATOR VS. DATE

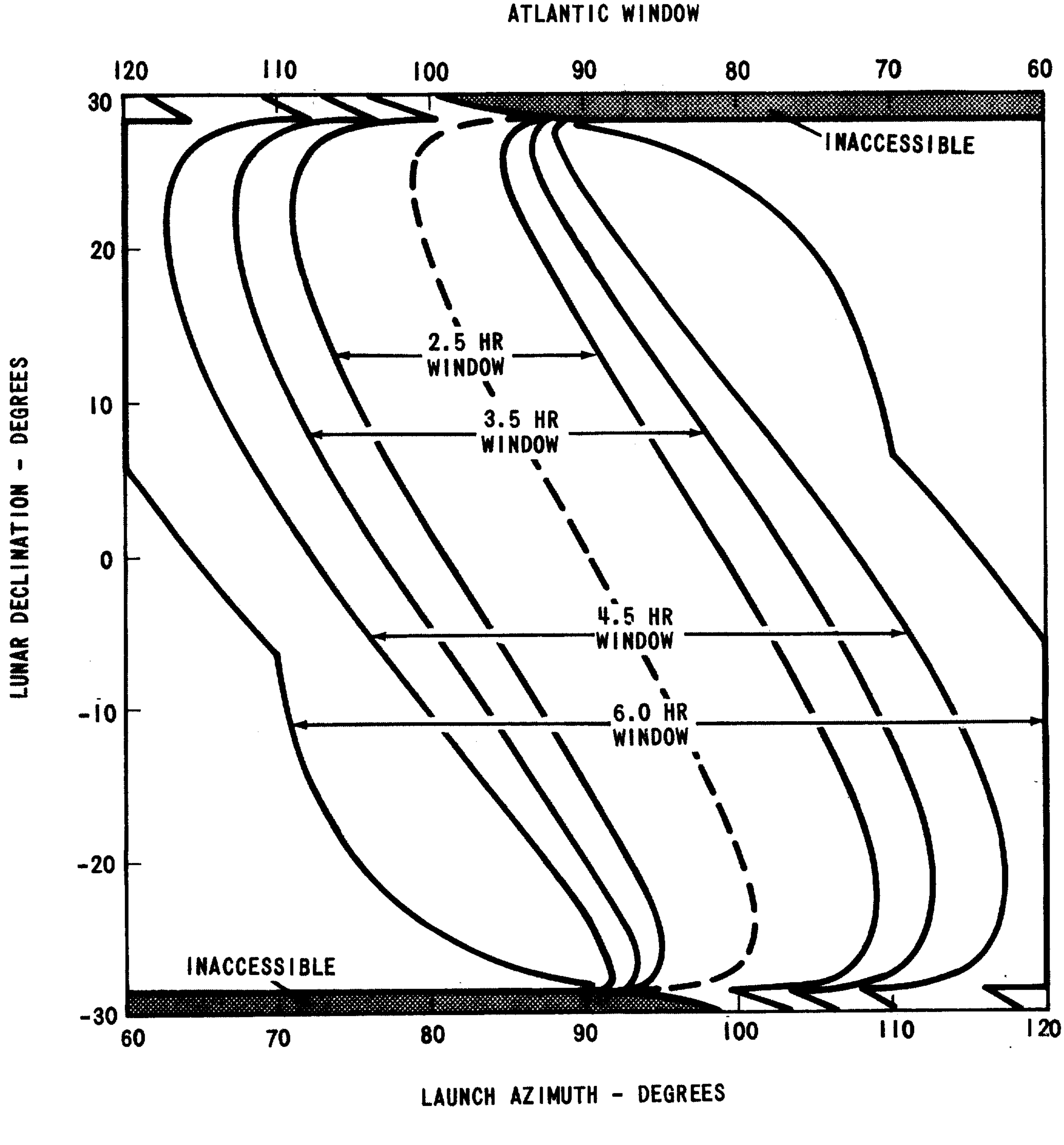


FIGURE 4 - "BEST" LAUNCH AZIMUTH RANGES FOR VARIOUS LUNAR DECLINATIONS (FOR LAUNCH WINDOWS OF 2.5, 3.5, 4.5, 6.0 HRS. DURATION)

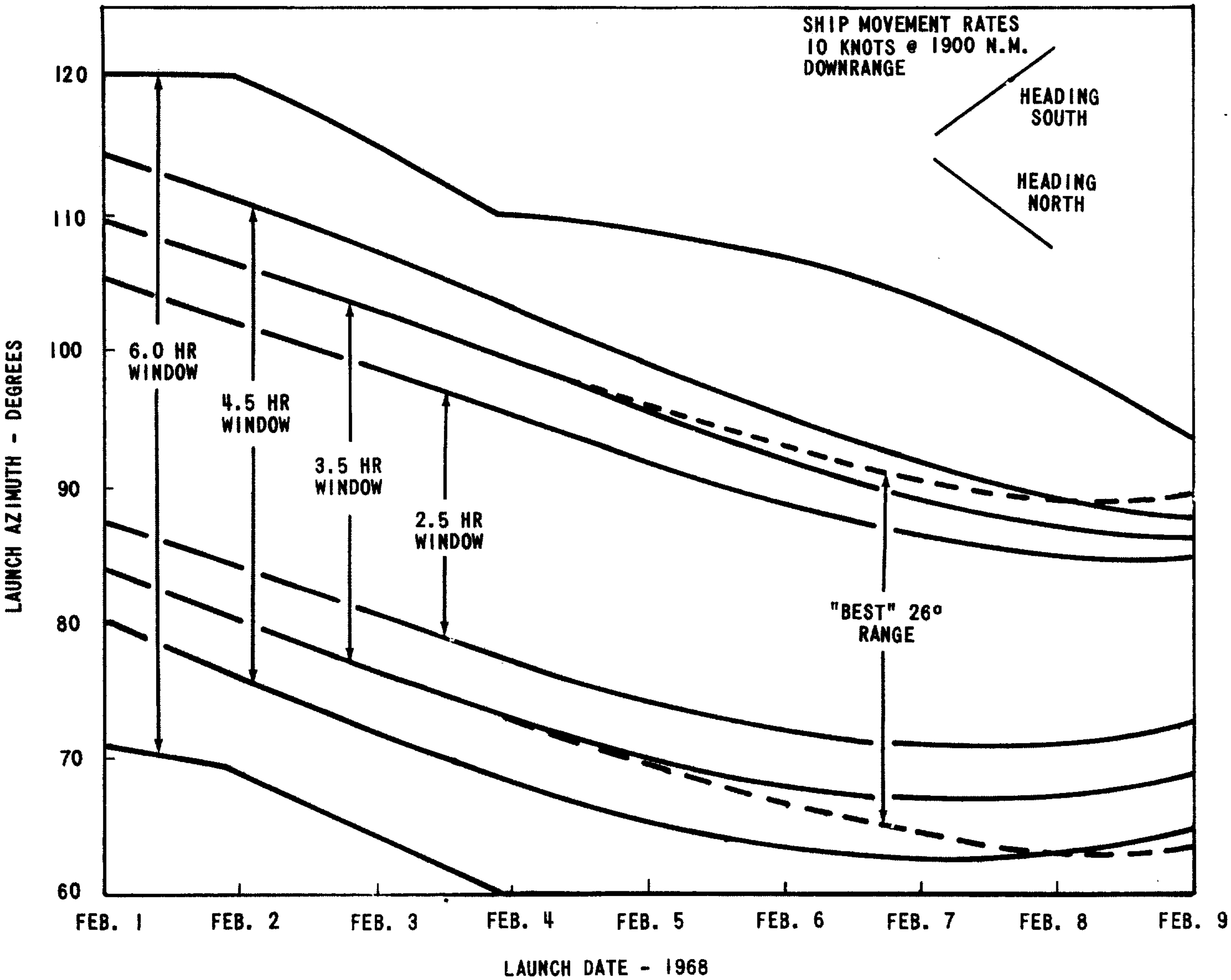


FIGURE 5 - "BEST" LAUNCH AZIMUTHS FOR FEBRUARY, 1968 (PACIFIC WINDOW)

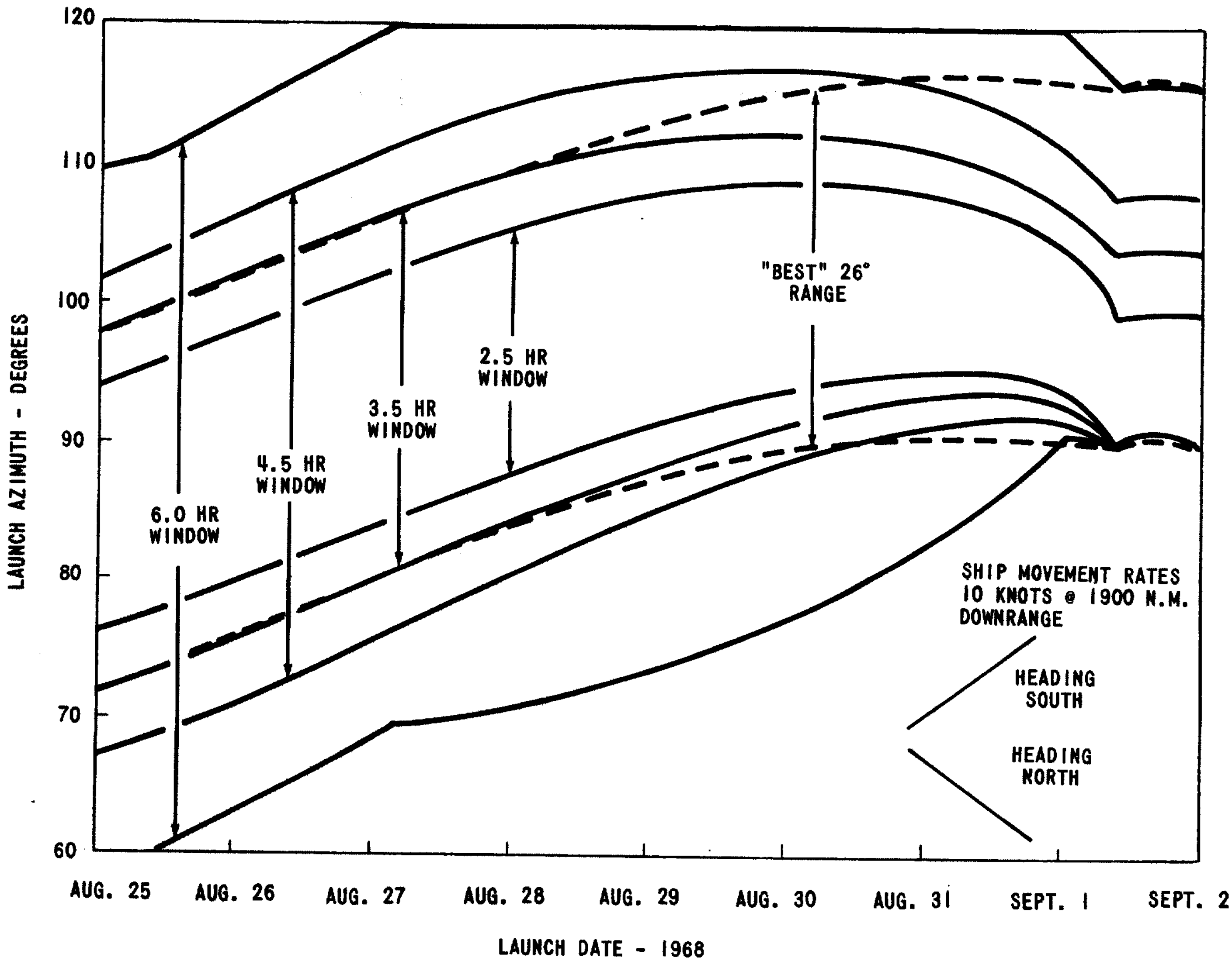
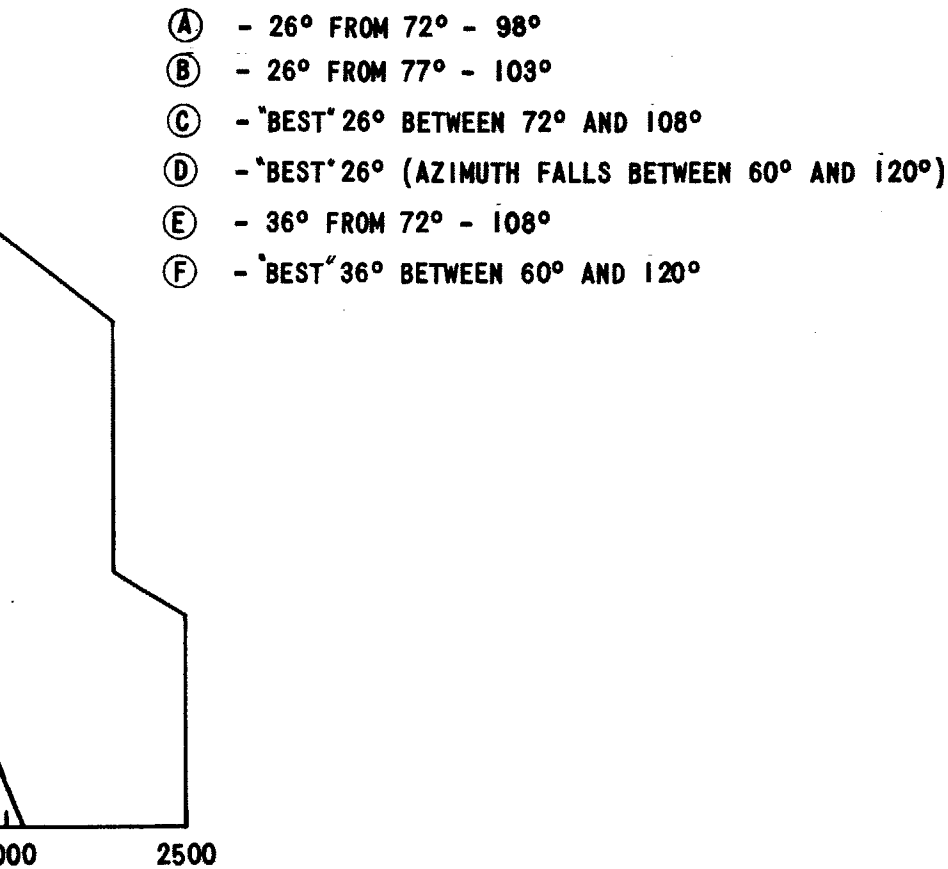
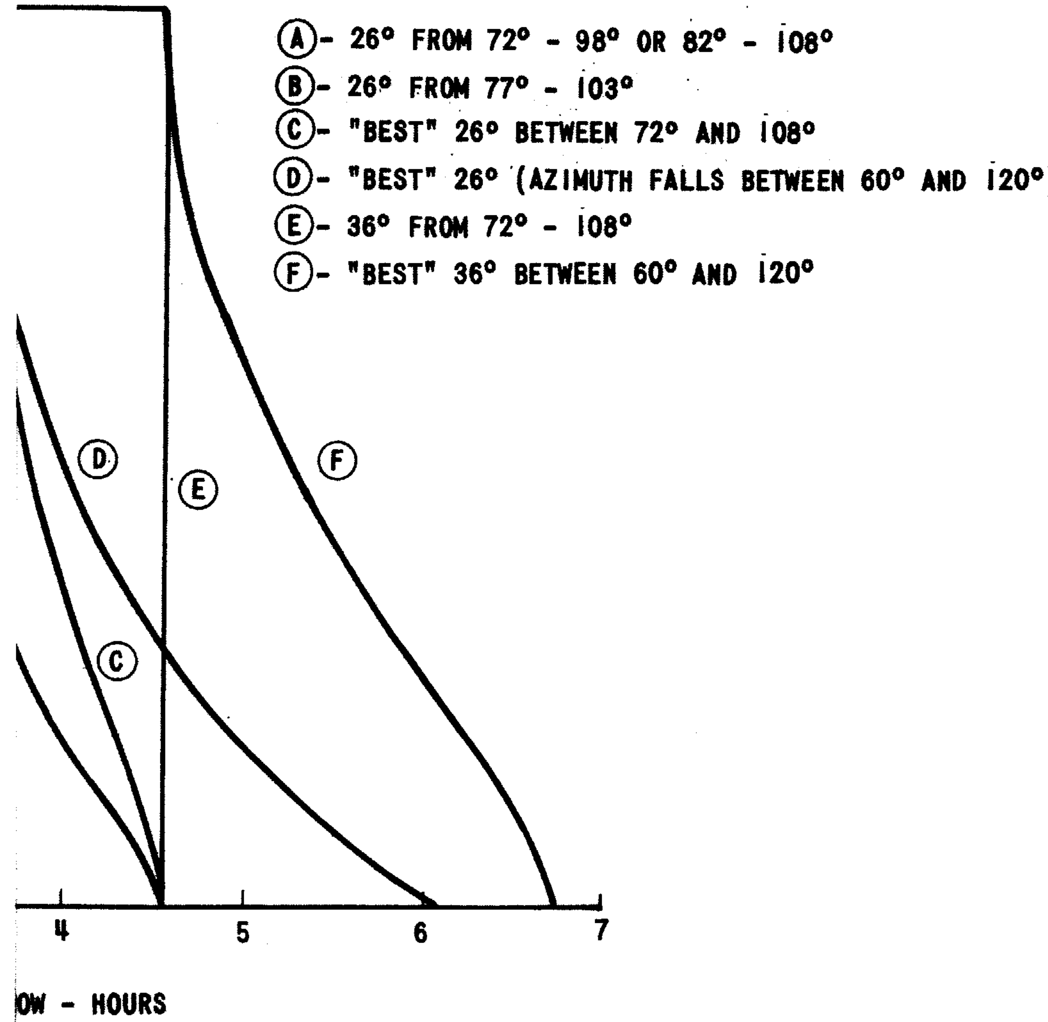


FIGURE 6 - "BEST" LAUNCH AZIMUTHS FOR AUGUST, 1968 (PACIFIC WINDOW)



AD LOSSES FOR 1968 - 1970
)



OF VARIOUS LENGTHS
LUNAR ORBIT INCLINATION ASSUMED)

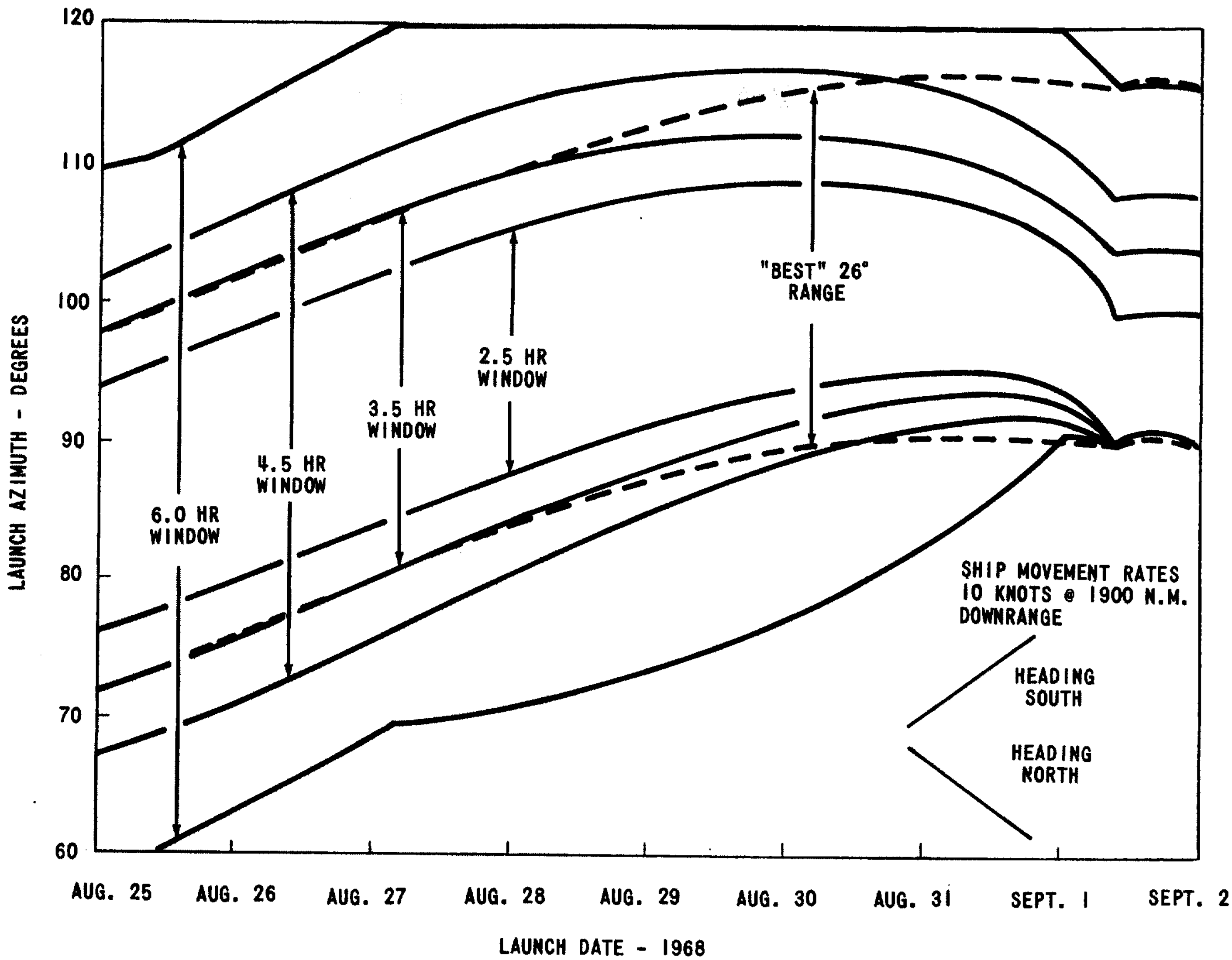


FIGURE 6 - "BEST" LAUNCH AZIMUTHS FOR AUGUST, 1968 (PACIFIC WINDOW)

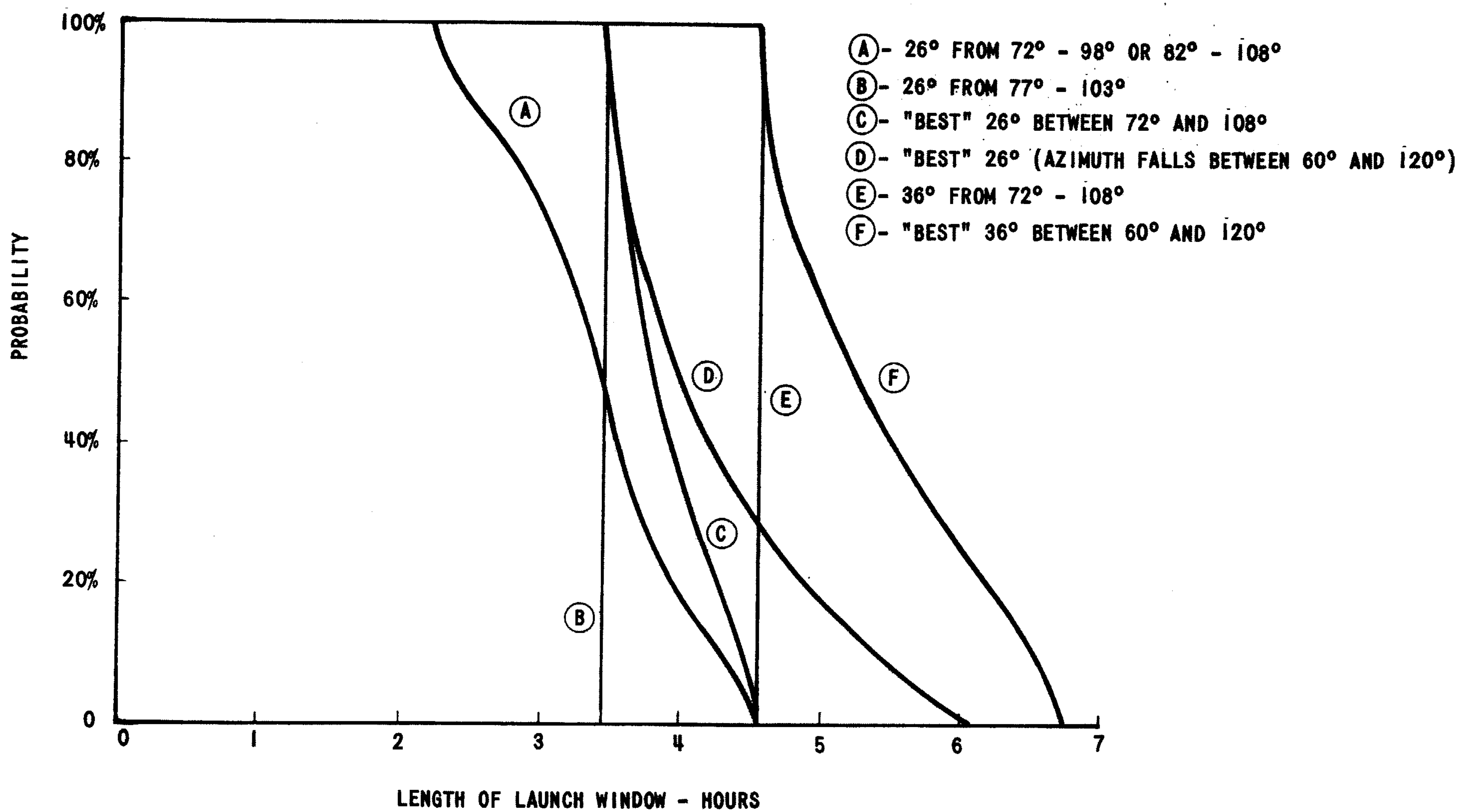


FIGURE 7 - PROBABILITY OF LAUNCH WINDOWS OF VARIOUS LENGTHS
(1968-1970 TIME PERIOD; 28.5° LUNAR ORBIT INCLINATION ASSUMED)

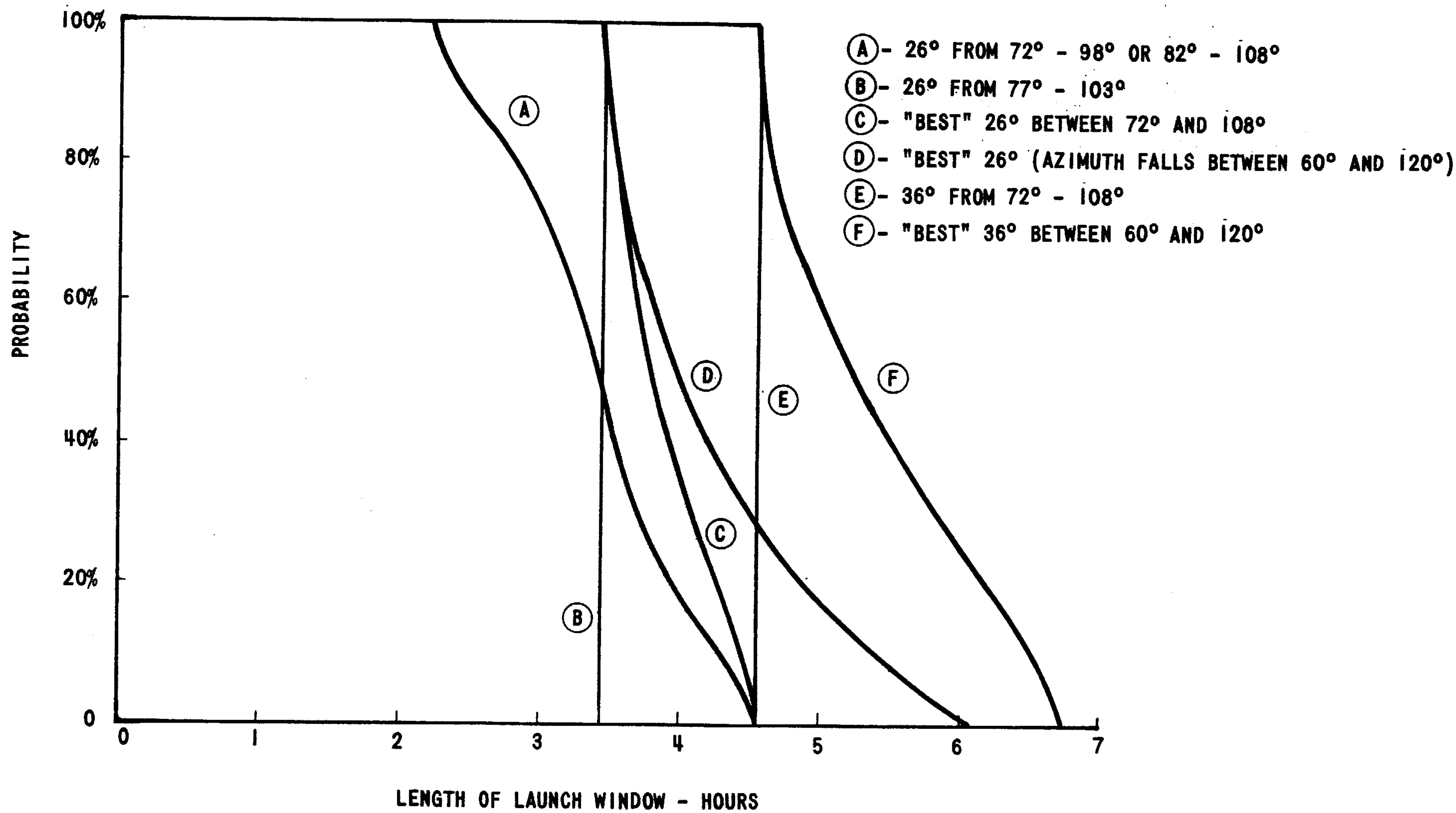


FIGURE 7 - PROBABILITY OF LAUNCH WINDOWS OF VARIOUS LENGTHS (1968-1970 TIME PERIOD; 28.5° LUNAR ORBIT INCLINATION ASSUMED)

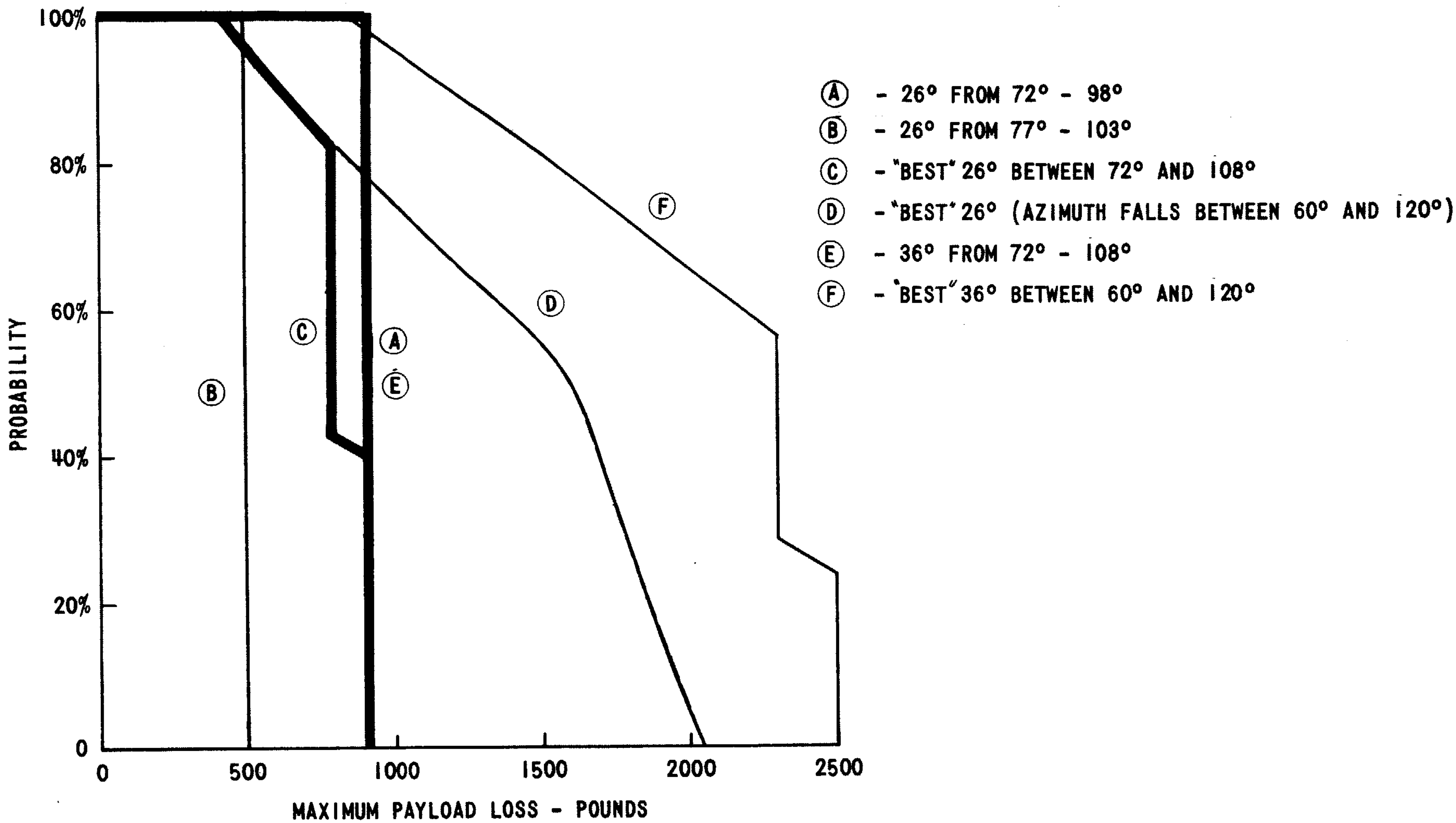


FIGURE 9 - PROBABILITY OF VARIOUS MAXIMUM LAUNCH VEHICLE PAYLOAD LOSSES FOR 1968 - 1970
(COMPARED TO 90° LAUNCH AZIMUTH)

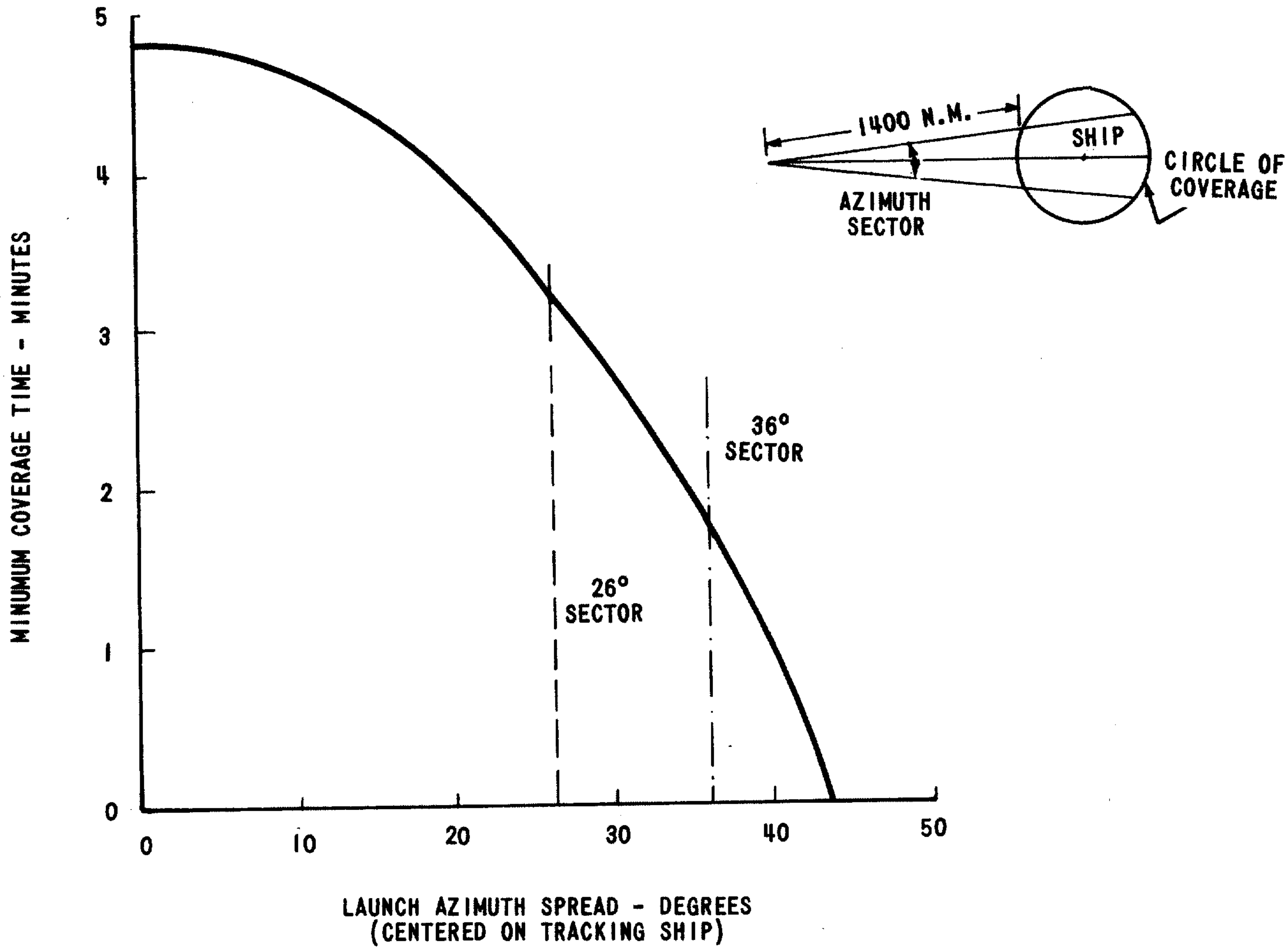


FIGURE 10 - MINIMUM INSERTION COVERAGE TIMES FOR VARIOUS AZIMUTH SECTORS
(100 N.M. PARKING ORBIT, 5° MASKING ASSUMED)

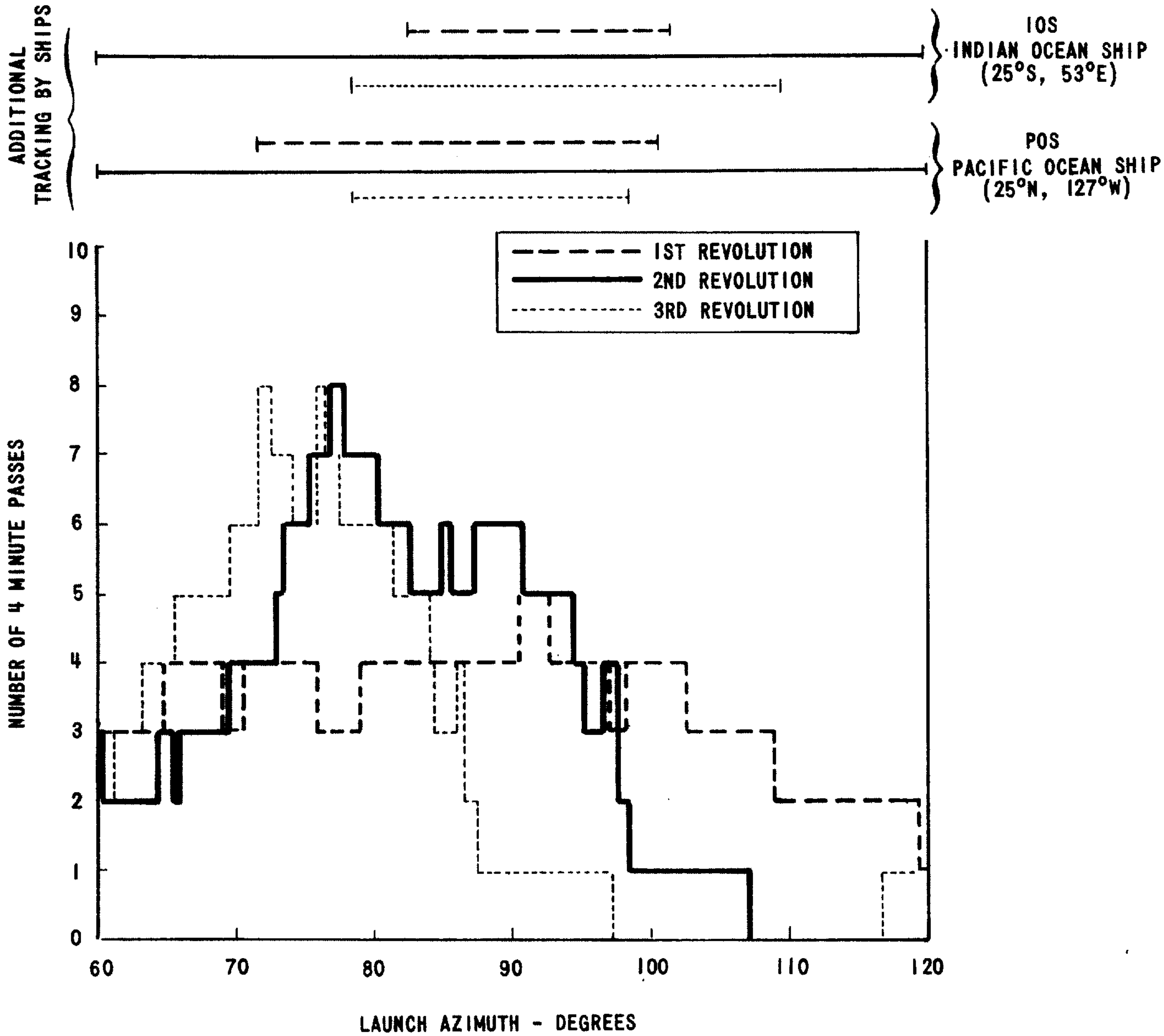


FIGURE 11 - NUMBER OF 4 MINUTE TRACKING PASSES PER REVOLUTION FOR VARIOUS LAUNCH AZIMUTHS (100 N.M. CIRCULAR ORBIT, 5° MASKING, 14 USB LAND STATIONS CONSIDERED)

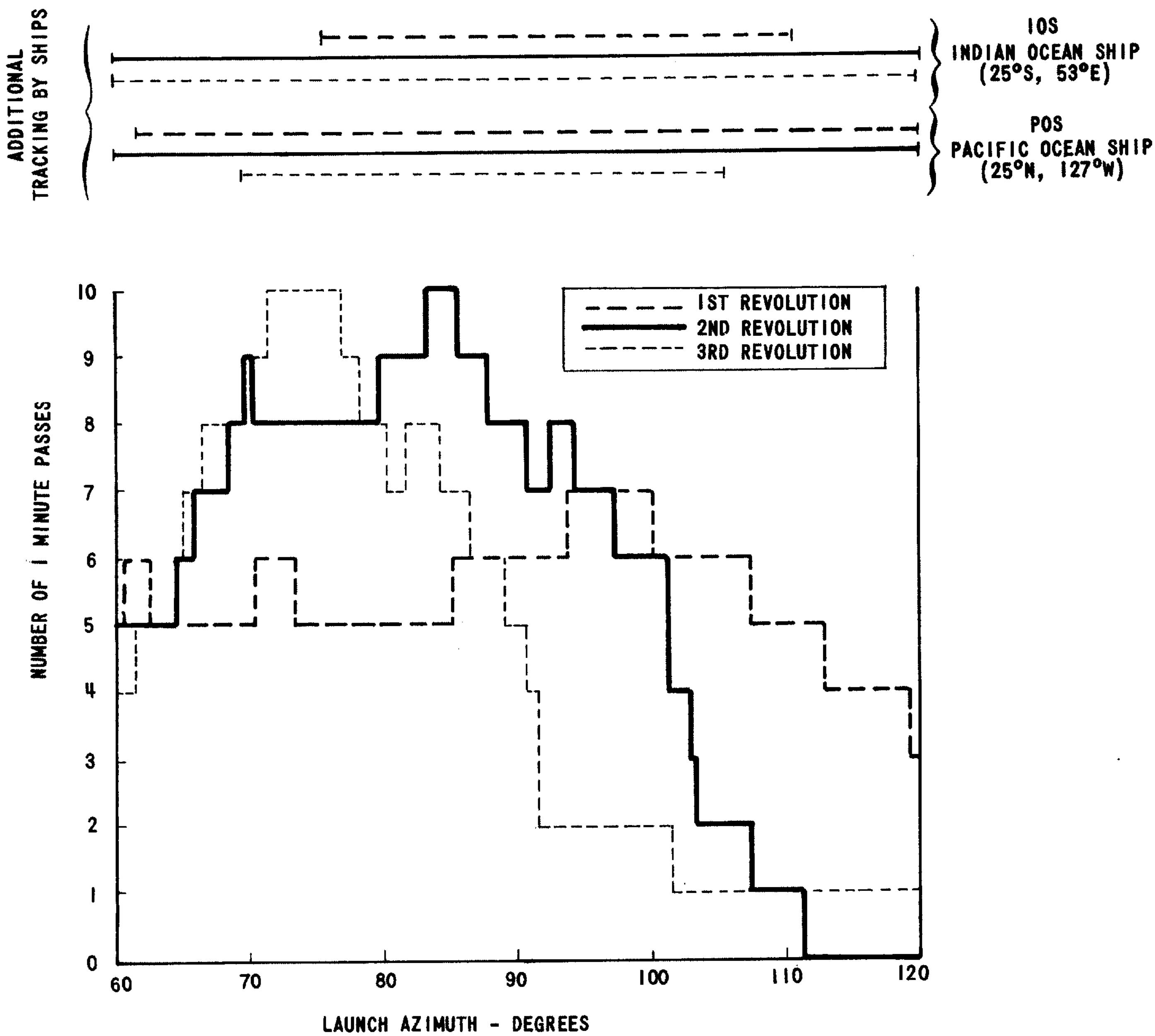


FIGURE 12 - NUMBER OF 1 MINUTE TRACKING PASSES PER REVOLUTION FOR VARIOUS LAUNCH AZIMUTHS (100 N.M. CIRCULAR ORBIT, 5° MASKING, 14 USB LAND STATIONS CONSIDERED)

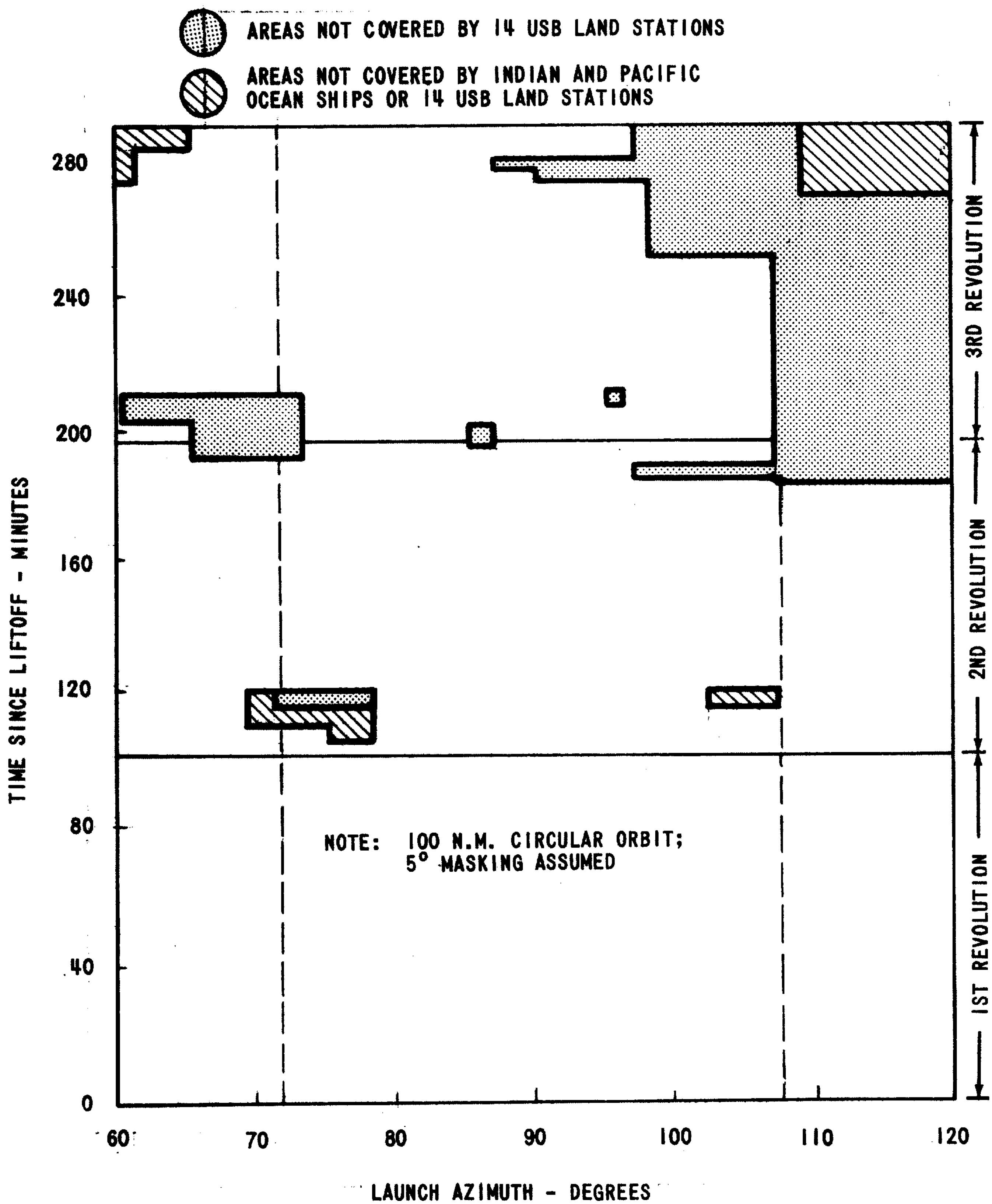


FIGURE 13 - REGIONS LACKING FOUR-MINUTE TRACKING PASSES BETWEEN 90 AND 30 MINUTES BEFORE INJECTION

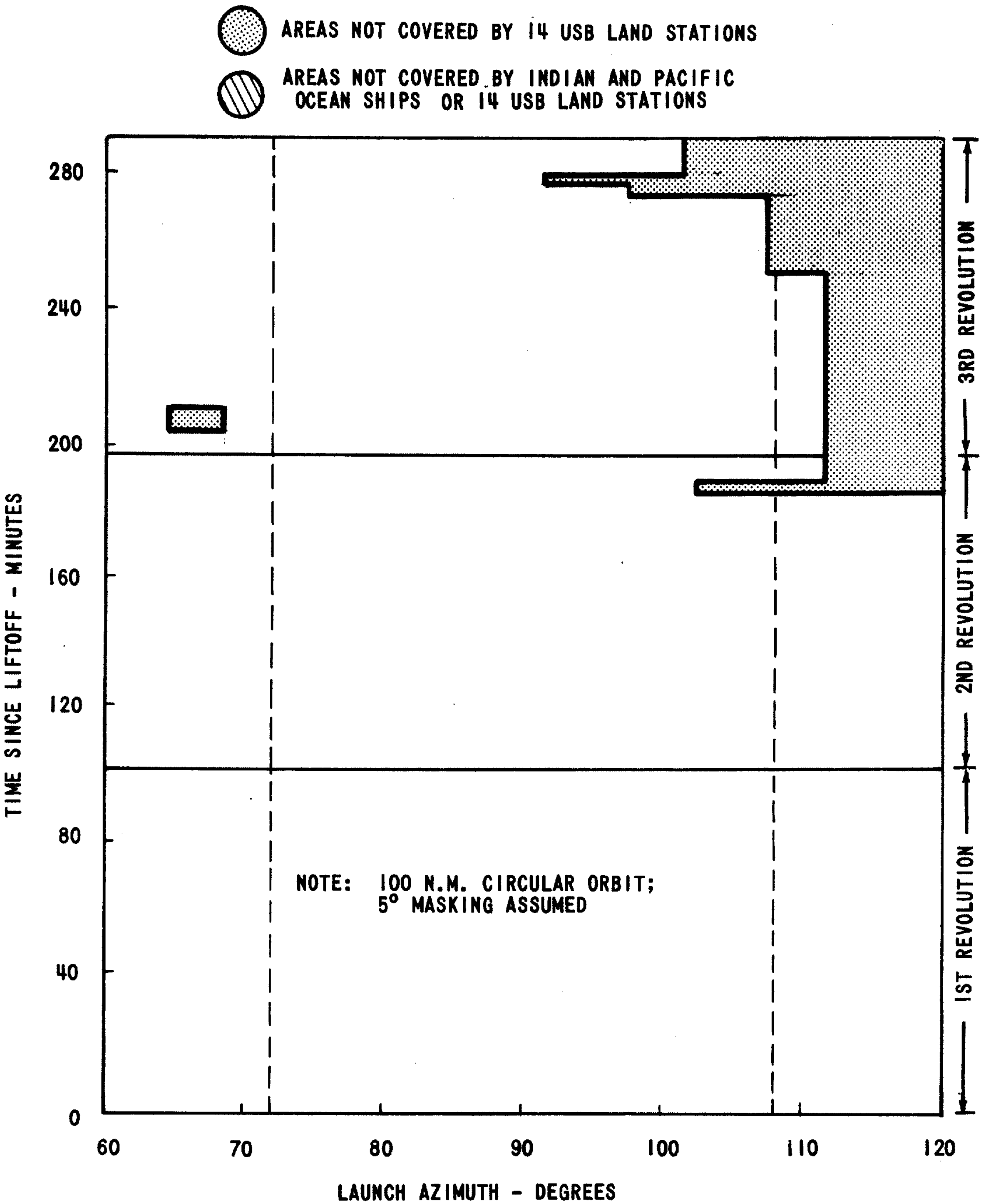


FIGURE 14 - REGIONS LACKING ONE-MINUTE TRACKING PASSES BETWEEN 90 AND 30 MINUTES BEFORE INJECTION